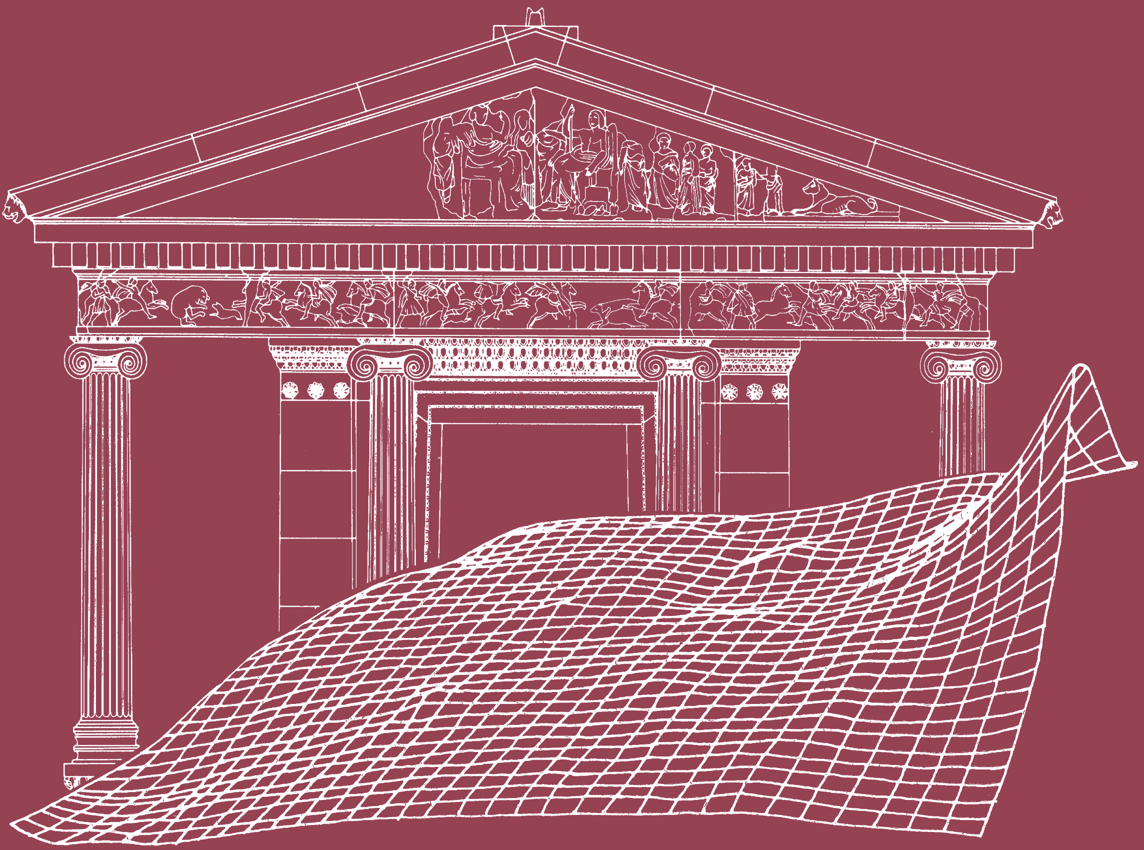

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FROM MINERALS TO ARTEFACTS: THE ROLE AND CHALLENGES OF 3D MODELLING

1. Introduction

In the historical context in which we find ourselves today, amidst an ongoing pandemic that strongly limits the freedom of individuals, 3D and augmented reality can play an important role in freeing the art and culture that are presently ‘trapped’ in museums, thus allowing them to be accessible from everyone’s homes. During recent years, we have witnessed an increase in 3D modelling, and more specifically the use of photogrammetry, as a tool to virtualize objects and artefacts usually stored and not on display in exhibitions. The new technologies and software available are now within everyone’s reach and budget, making the use of augmented reality (Pikov *et al.* 2015; Capuano *et al.* 2016) and, more generally, an approach to studying through the virtual, easily accessible. Today, it is indeed possible to view and ‘handle’ practically any object, artefact, or mineral of interest, while remaining comfortably seated at home several thousand kilometres away. This has been made possible thanks to the creation of three-dimensional models based off the original object and its virtual projection (Shcherbinin 2018).

The construction of 3D models can be achieved by the composition of a series of many photographs (of the object or area of interest) taken from different angles, using either common cameras or more complex and remotely manoeuvrable systems, such as Unmanned Aircraft System (UAS), making it a versatile instrument applicable to different fields, e.g., from the documentation of Cultural Heritage (McCarthy *et al.* 2014), to forensic medicine (Thali *et al.* 2003). With photogrammetry, it is in fact possible to extrapolate metric information starting from two-dimensional data such as images (Forlani *et al.* 2015). The photographs are then reworked by a specific software (there are many on the market) for 3D modelling and reconstruction (Kersten *et al.* 2018; Monna *et al.* 2018).

It is also possible to use laser scanners for the close-range construction of three-dimensional objects, which provide a high-quality and relatively quick data acquisition, but involves a much higher expense than the cheaper and more versatile three-dimensional photogrammetry (Andrés *et al.* 2012). 3D modelling has proven itself to be an affordable and almost ready to use method to create 3D models of objects of any sort and shape complexity and make it visible and usable by everybody with Internet access.

Although photogrammetry has existed for many years, it is a constantly changing method in continous development, and these characteristics make it a technique with unlimited resources. Unfortunately, although 3D modelling is an effective and economical tool for the virtualization of museum objects and artefacts, in our recent work (Aquino *et al.* 2020a) we have shown that its ease of use is not without specific problems. In fact, some of the studied objects with reflective or transparent surfaces hindered the camera from focusing accurately and consequently generated problems in the construction of the 3D model. These limitations, together with the problems related to the processing of small components with highly complex shapes, have also been reviewed in the literature (Esmaeili *et al.* 2016).

This work primarily concerns the data acquisition and 3D modelling of objects (Medina *et al.* 2020) of varying complexity, coming from different museums and areas of Tuscany. We also focused on photogrammetry as a three-dimensional modelling tool for Cultural Heritage (Pavlidis *et al.* 2007), and on data acquisition and scanning problems encountered during the preparatory work.

2. Materials and methods

In this work, we have considered and studied some stone objects, minerals, and artefacts from different areas of Tuscany. For simplicity, we will report only a few as examples: among the mineral samples, we chose a single crystal of calcite and a single crystal of feldspar, both kindly provided by the Natural History Museum of the University of Florence, and an aggregate of brown calcite crystals from the Natural History Museum of the University of Pisa; among the rock samples, we chose a piece of limestone from Monte Morello Formation (formerly Alberese) from a private collection and a small stone head, belonging to the Targioni Tozzetti collection of the Natural History Museum of the University of Florence.

The calcite crystal (inv. MSN-Fi G47378) is a sample of Icelandic spar 8×5×5 cm in size, with pink colour and a milky translucent transparency, coming from Durango, Mexico; the feldspar crystal (inv. MSN-Fi G41641) is an orthoclase crystal 16×5×5 cm in size belonging to the Ponis collection and coming from a Brazilian pegmatite. They represent, among those we have studied, the simplest of geometric shapes. The block of limestone is a marly limestone coming from Mt. Morello, in the surroundings of Florence, widely used in the past to produce lime (Aquino *et al.* 2019; Fratini *et al.* 2020; Lezzerini *et al.* 2020). The carved stone head, from the Etruscan period, presumably coming from Volterra, is made of a calcarenite, like the ‘Panchina’ stone, a highly porous stone with medium sized grains, rich in organogenic carbonate fragments (Lezzerini 2005; Aquino *et al.* 2020b).

The 3D modelling technique used for this work is photogrammetry, a method of 3D reconstruction that uses numerous images and data processing

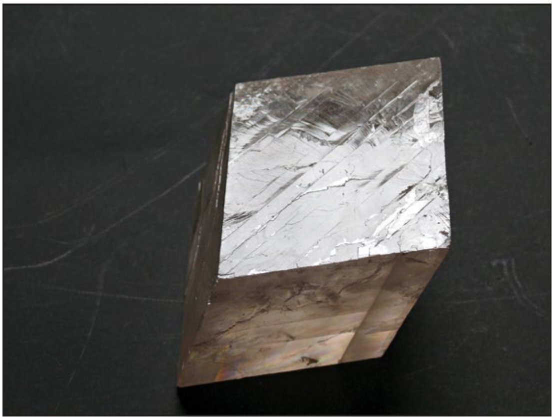

Fig. 1 – Calcite, var. Iceland spar (MSN-Fi G47378). The transparent and reflecting surfaces are clearly visible.

software as working tools. For this work, we therefore collected a series of photos (not less than one hundred images per object) to build the archive from which to process our three-dimensional model. The equipment used for capturing images and building our starting database were a LEICA V-LUX 1 and a NIKON D500 camera, equipped with a high-performance LEICA DC VARIO-ELMARIT 1:2.8-3.7/7.4-88.8 ASPH zoom lens and a Nikon 16-80mm f/2.8-4 VR lens, respectively. In particular, we used the LEICA camera to capture photos of the calcite, feldspar and limestone. In total, over 300 photographs were taken of these objects in natural light conditions and using a dark blue shelf as a support base. The photographs were taken at different angles while rotating 360° around the object: first at 0°, then at about 15°, 30°, 45°, 60°, 75° and finally vertically at 90°, following the model schematized in Fig. 2.

Additionally, the studied object was rotated in different positions in order to ensure the coverage of all surfaces during photo acquisition. The photographs of the limestone head, on the other hand, were taken in the photographic laboratory of the Natural History Museum of the University of Florence with professional photographic equipment and screened artificial light coming from about 80°. The head was positioned on a white graduated rotating plate placed in front of a uniform white photographic background. The photographs were taken using the NIKON D500 on a tripod by varying the height in order to respect the previous angles except for the photos taken from above, which were handheld. Once the pictures were captured from all angles, the object was turned upside down. This procedure allows the software to correctly align all of the images by elaborating the recognition

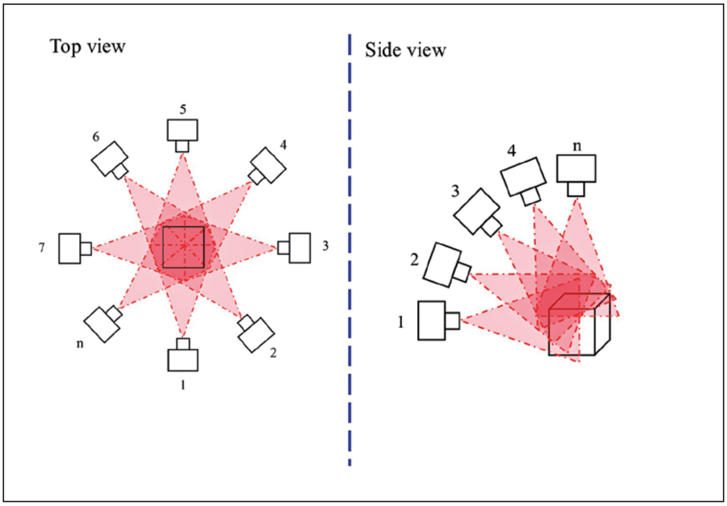

Fig. 2 – Schematic model of photo acquisition procedure.

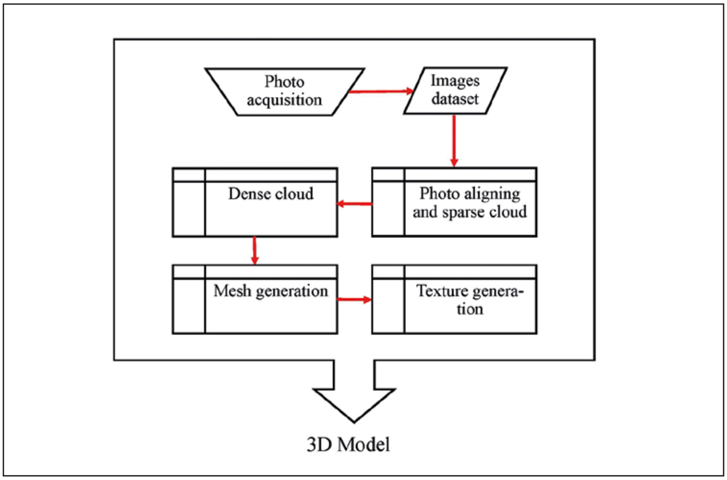

Fig. 3 – Schematic flow-chart of 3D model reconstruction.

of the common points (CP) for each surface and of each image, enabling the construction of the 3D point cloud. To this end, it is essential to ensure a minimum image overlap of at least 60%.

Once we obtained the necessary photographic database, we proceeded to create the three-dimensional model for each of the studied objects. The software

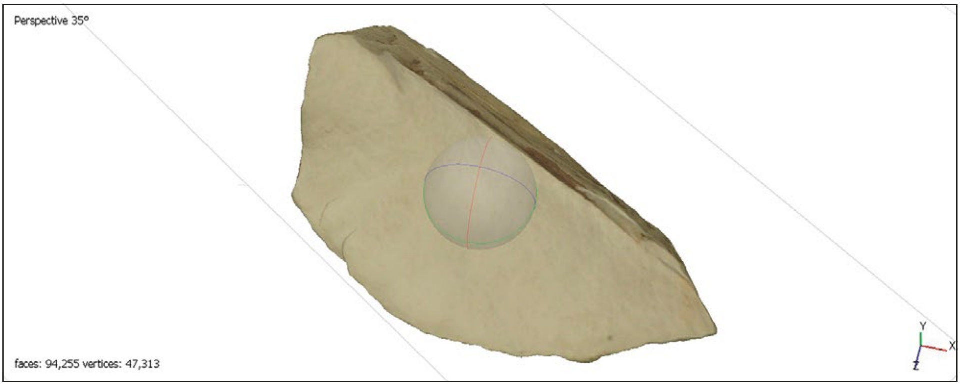

Fig. 4 – Texture model of the selected limestone block. The lack of transparent and reflecting surfaces and a simple geometric shape allowed for an easy processing of the 3D model.

used for processing the photographic archive was Metashape, produced by Agisoft, version 1.6.4. The processing was carried out using high-performance workstations. The work phases began with the alignment of the photos, the construction of the dense point cloud and of the mesh, and finalized with the construction and application of the textural model as schematized in Fig. 3. This process is partially automatic, except for the verification of the requirements at the end of each step which does not normally require manual editing. Each model took between 30 to 45 minutes to complete processing.

3. RESULTS

The three-dimensional model of the limestone (Fig. 4) together with those of the feldspar and of the aggregate of brown calcite crystals (Fig. 7) turned out to be easiest to process. Thanks to their simple, albeit particular geometric shape, together with the lack of reflective surfaces and their opaque colour, no final finishing work was necessary. The 3D model is a faithful representation of the original sample.

The calcarenite head, given its greater complexity compared to the other studied objects, required a larger amount of photos in order to build the archive. However, the substantial number of photos, the opaque colour, and the absence of transparent or reflective surfaces were not enough to achieve a perfect three-dimensional model reconstruction. Moreover, probably due to the use of a different image acquisition method compared to that of the crystals (here a turntable was used as a support surface), both the dense point cloud and the mesh have included some portions of the support base into the creation of the final model (Fig. 5).

Fig. 5 – Carved calcarenite head, Etruscan period (MSN-Fi): 3D model with traces of the white background used.

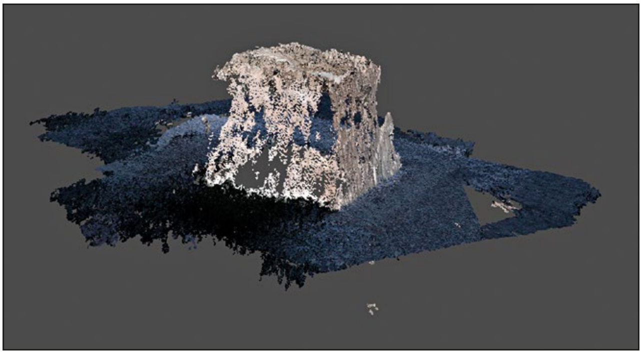

Fig. 6 – Calcite crystal 3D model affected by deficiencies in the point cloud. Note that the software has not been able to detect the difference between the crystal and the surface on which the crystal was laying.

These defects are generated due to the inability of the software to distinguish the specific characteristics of each neighbouring photo and to recognize the same characteristics to establish the control points. This may be due to human error both in planning the photography setup and in taking an excessive number of pictures without proper angle variations. This problem could be overcome by using a support surface with irregular visual characteristics instead of a surface with uniform colour.

As reported in literature, further problems in the construction of 3D models were encountered in the objects with transparent or reflective surfaces,

Fig. 7 – Aggregate of brown calcite crystals.

specifically in the case of calcite. In fact, the calcite crystal we studied under direct light conditions, both natural and artificial, gave rise to numerous effects of flicker and shimmer, caused not only by its reflective and transparent surfaces, but also by the growth planes and internal inclusions of the crystal (Fig. 6). We managed to partially solve the problem by utilising a light shield and by switching to the manual focus setting on the camera. Seemingly, the growth planes of the crystals, especially in the case of high transparency, do not allow a correct focusing, as it focuses on the portions that are more internal than on the surface of the crystal.

4. Conclusions

Although the complexity of studied objects was quite similar, the feldspar crystal was the easiest object to digitize, followed by the calcarenite head. In general, we noticed that, especially for the more complex objects, it is better to have higher quality images than just a higher quantity. Having a large number of photographs can lead to errors in the creation of the dense point cloud and, therefore, of the mesh. We have also noticed that both the type of lighting and of work surface used, affect the subsequent ability of the software to process the photographic archive. In order to avoid photo editing either in the phase following the creation of the model, or even before processing, a simple way to get around the problem is to insert a visual disturbance onto the work surface, such as a pen.

Furthermore, the software will recognize the disturbance as part of the background and not of the studied object, thus proceeding to its elimination. So, the tool of photogrammetry for the purposes of constructing three-dimensional models is low-cost, easy-to-access, and saves time during the editing process, making it an efficient and advantageous technique for the reconstruction of objects, artefacts and items of cultural interest that can then be made available for public display, or remote access.

Some of the current practices for resolving issues regarding the image acquisition of objects with numerous transparent and/or reflective surfaces involve the application of harmless matting lacquers that can be easily removed from the object, or taking photos with the aid of a circular polarizer, which although it does not completely remove reflections, it effectively attenuates most of them. Nevertheless, for the future, it will be necessary to develop faster and more efficient methods for the image acquisition of objects for the purposes of 3D modelling.

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ABSTRACT

Over the past decade, we have witnessed an increase in the use of technology, through the creation of virtual itineraries and exhibitions, as a tool to guarantee and increase the usability of museums and more generally of artistic and historical works. In fact, it often happens that many works of art and artefacts of archaeological and cultural importance are not accessible to the public, either because they are kept in museum deposits or because they are difficult to access. In a context such as the current one, however, with an ongoing pandemic that forces most of the population to remain at home, the virtualization of museums, and historical and cultural heritage, becomes the main tool for exploring and enhancing culture. Among the various methodologies used for the creation of three-dimensional models, photogrammetry stands out for ease of use and low cost. This article analyses the use of photogrammetry in 3D modelling, focusing on pros and cons as a rapid, low-cost tool, which makes artworks virtually accessible to the public via museum websites and social network forums.

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